Glacial Lake Licking: Late-Glacial Drainage Diversion and the Formation of Black Hand Gorge, Licking County, Ohio[1]

TOD A. FROLKING AND MATTHEW A. PACHELL[2], Department of Geology and Geography, Denison University, Granville, OH 43023; Anadarko Petroleum Corporation, The Woodlands, TX 77380

ABSTRACT. Numerous narrow, steep-walled valleys cut through the uplands of the Glaciated Appalachian Plateaus section of east-central Ohio. In Licking County, eastward-advancing glacial ice blocked the west-flowing paleo drainage east of Newark forming Glacial Lake Licking. Lake waters ultimately overtopped a drainage divide south of Hanover causing the erosion of Black Hand Gorge and reversal of the Licking River drainage. Cutbanks and cores into late-Wisconsinan terraces along the Licking River and its tributaries above the Gorge reveal dense, laminated (± 1.0 mm) to massive, calcareous, gray lacustrine silt disconformably overlain by 1.0-6.0+ m of oxidized fluvial sand and gravel overlain in turn by sandy silt (Chili loam soil). Lacustrine silt has been found from elevations of 228 m (748 ft) above sea level in cores in the Licking River floodplain to 255 m (838 ft) in a small lateral tributary. The 230 m (755 ft) elevation of the modern Gorge channel bed indicates at least 25 m of incision since the lake was impounded. Two radiometric dates (33,440 ± 1060 and 21,660 ± 120 years BP) as well as stratigraphic and pedogenic relationships indicate that Glacial Lake Licking was impounded in the late Wisconsinan and that gorge cutting occurred relatively early during the last glacial maximum. No weathering zone, indicating a significant period of subaerial exposure, has been noted either at the silt/gravel contact or within the fluvial gravel.

OHIO J SCI 106 (3):103-111, 2006

INTRODUCTION

The Glaciated Allegheny Plateaus physiographic region (Brockman 1998) affords some of Ohio's most varied and rugged topography due in part to the interactions of resistant bedrock with geologically recent glacially induced drainage modifications. Dammed or displaced streams have produced numerous "youthful" steep-walled valleys with bedrock channels, massive outcrops, high local relief, and often isolated vegetation communities. Many of these areas are now state parks, natural areas, and scenic rivers. Most of these steep, narrow valleys in east-central Ohio were formed as west- or north-flowing streams in preglacial or early Pleistocene valleys were blocked by the advance of an ice sheet from the north or west. Glacial lakes then expanded until new outlets were cut through topographic lows in the impounded drainage basins. Some prominent narrow valleys in east-central Ohio include Clear Fork of the Mohican River (State Park) southwest of Loudonville, in Ashland County; the Kokosing River (State Scenic River) west of Gambier, in Knox County; Black Hand Gorge (State Nature Preserve) on the Licking River between Hanover and Toboso in Licking County; Jonathan Creek east of Mt. Perry in Perry County; Little Rush Creek north of Bremen, in Fairfield County; and Clear Creek west of Rockbridge, in Hocking County (Fig. 1). Black Hand Gorge (historically referred to as Black Hand Narrows) is notable both for its length of about 3.6 km and for its narrow width of 40-50 m through the heart of the Gorge (Fig. 2). Many other regional gorges have broader valley floors perhaps indicative of older ages, weaker bedrock or greater stream erosion power over time.

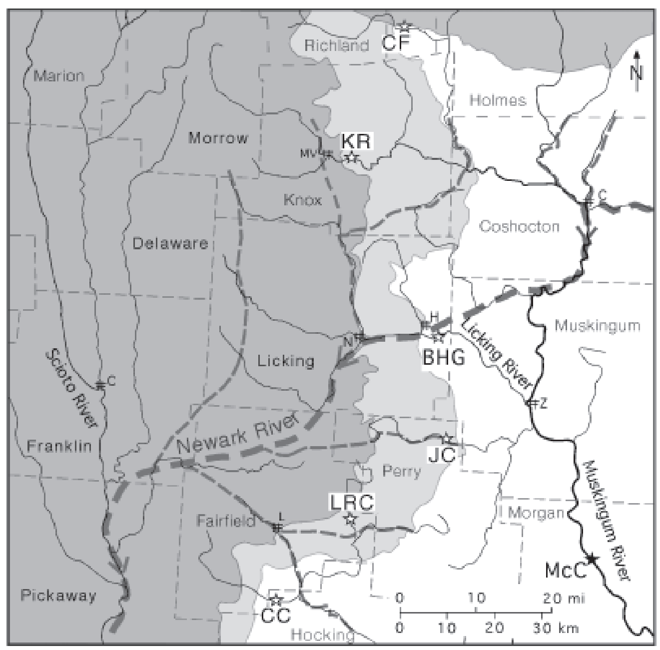

FIGURE 1. Regional map of modern (black) and deep-stage (dashed) drainage patterns of east central Ohio showing the approximate limits of Illinoian (light gray) and late-Wisconsinan (dark gray) glacial deposits (ice margins from Pavey and others 1999), several prominent bedrock narrows (CF = Clear Fork, KR = Kokosing River, BHG = Black Hand Gorge, JC = Jonathan Creek, LRC = Little Rush Creek, CC = Clear Creek, McC = McConnelsville), cities (MV = Mount Vernon, C = Coshocton, Columbus, N = Newark, Z = Zanesville, L = Lancaster), and the town of Hanover (H) just north of Blackhand Gorge.

Black Hand Gorge is the type locality for the Black

[1]Manuscript received 16 October 2004 and in revised form 15 December 2005 (#04-21).

[2]Previously at the Department of Geology, Utah State University, Logan, UT 84322

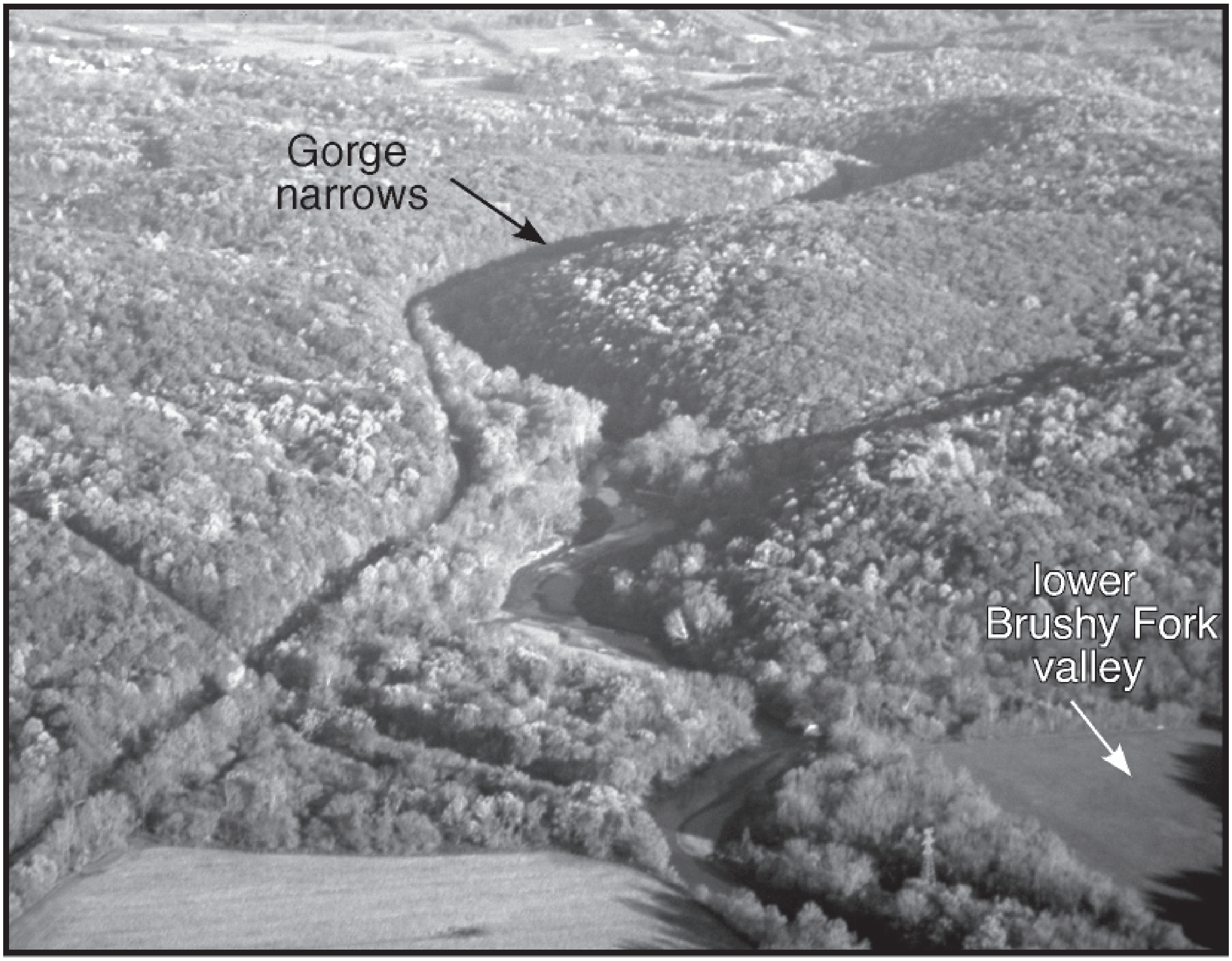

FIGURE 2. Air photo looking east to Black Hand Gorge; the valley floor of the Licking River is in the foreground, lower Brushy Fork valley enters from the right (south), narrowest section of the gorge is indicated.

Hand Sandstone Member of the Mississippian upper Cuyahoga Formation that forms the steep, inner portion (20+ m of relief) of the Gorge (Malcuit and Bork 1987). The sheet-like members of the superjacent Logan Formation form the more modest upper slopes of the Gorge up to elevations of 305 to 315 m (1000 to 1040 ft) with the Pennsylvanian Pottsville Formation forming the higher ridge tops in the area (Bork and Malcuit 1979; DeLong 1972).

Black Hand Gorge and the Licking River system were significant to Ohio's socioeconomic history with the development of the Ohio-Erie Canal. The canal utilized the Gorge and followed numerous stretches of now-abandoned, deeply buried paleo valleys. Portions of the modern Licking River and the North and South Fork tributaries occupy broad valleys of the Teays-age Cambridge and Groveport rivers valleys. These valleys were subsequently deepened by the Deep Stage Newark and Utica rivers (Stout and others 1943; Coffee 1958; Dove 1960). The timing of these deep valley-forming phases remains uncertain. Workers now assign much of the Teays-Mahomet drainage development to the early Pleistocene (Melhorn and Kempton 1991) with the Deep Stage incision linked to the development of the Ohio River system (Teller and Goldthwait 1991). The eventual development of Black Hand Gorge parallel to and immediately south of the former Newark valley must have occurred after the creation of the Muskingum River, which allowed for regional drainage to the southeast into the Ohio River (Fig. 1). The development of the Muskingum River is thought to have been caused by the damming of the Deep Stage Newark River by glacial ice at Hanover and the breaching of a bedrock divide near McConnelsville in Morgan County (Tight 1894a).

Glacial, glaciofluvial, and deltaic deposits near the eastern limit of Illinoian ice (Forsyth 1966; Pavey and others 1999) at Hanover locally filled the Deep Stage Newark valley to an elevation of 275 m (900 ft) (Pavey 1995; see also early discussions by Leverett 1902 and Carney 1907). Dove (1960) and later Malcuit and Bork (1987) proposed that Black Hand Gorge was primarily cut during a subsequent Illinoian phase when glacial ice blocked the Newark Valley somewhere to the west of Hanover and impounded water rose until the lowest point in the bedrock divide to the south was overtopped and incised by lake outflow. Forsyth (1966) mapped Wisconsinan lake deposits in Claylick and Brushy Fork valleys to the west of the Gorge (Fig. 3). If these sediments are Wisconsinan, their presence would preclude a full cutting of the Gorge during Illinoian time, but Forsyth provides no justification for the age of the material. The Licking County Soil Survey provides much information about the character and distribution of surficial materials in the region (Parkinson and others 1992). Numerous soil bodies with parent materials attributed to Wisconsinan glaciolacustrine deposits are mapped in tributary valleys to the Licking River between Newark and Black Hand Gorge, but again the age of the sediments is not justified.

Tight (1894b) coined the term *Lake Licking* for a large lake formed by glacial deposits blocking the paleovalley at Hanover to the east and the damming of the southwest-flowing paleodrainage by some undetermined glacial or interglacial agent to the southwest. This lake would have inundated present-day Newark and was thought to be responsible for the extensive flat terrain and fine-grained sediments in the vicinity of Buckeye Lake in the south-central portion of the county. This paper focuses on the distribution, stratigraphy, and ages of lacustrine and fluvial sediments immediately upstream (west) of Black Hand Gorge in the Licking valley and its tributaries (Fig. 3). The name *Glacial Lake Licking*, a modification of Tight's original usage, refers to the ice-dammed lake that led directly to the formation of Black Hand Gorge and the modern Licking River system. Field relationships, laboratory data, and two radiometric dates indicate that lacustrine sediments and overlying fluvial gravels upstream from the modern gorge are late Wisconsinan in age and thus the cutting of the Gorge occurred at that time. The gorge's narrow floor, steep inner walls, and actively incising side tributaries reflect its youth.

MATERIALS AND METHODS

Topographic maps and the Licking County Soil Survey (Parkinson and others 1992) were carefully examined to ascertain the distribution of relevant landforms

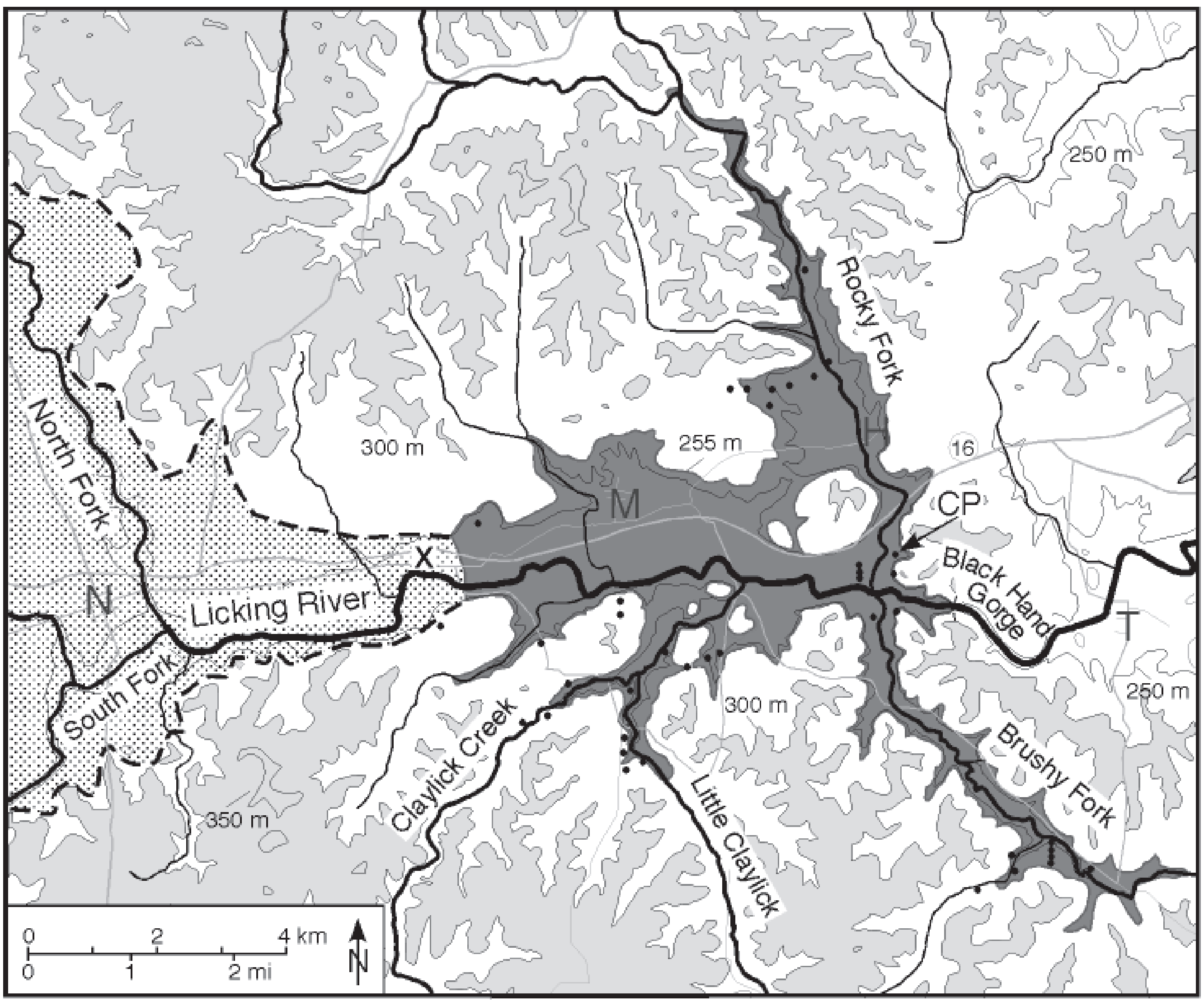

FIGURE 3. Map of Lower Licking River study area showing generalized terrain (50 m contours with uplands above 300 m in light gray) with modern drainage and valleys, field sites (dots locating cores and bank exposures, X locates Longaberger building, CP locates Cartnal-Postle site), approximate extent of glacial Lake Licking (255 m contour, dark gray), approximate location of Late-Wisconsinan ice maximum (stipling), and some roads and towns to aid in site location (N = Newark, M = Marne, H = Hanover, T = Toboso).

and materials including bedrock hills, Illinoian drift, Wisconsinan lacustrine, eolian and fluvial deposits, and Holocene floodplain deposits. Stream banks of the lower Licking River and its tributaries (Claylick, Little Claylick, Brushy Fork, and Rocky Fork) were examined for exposures of fine-grained, non-fluvial sediments by canoe and on foot. A trailer-mounted Giddings Probe was used on floodplains and terrace surfaces to core down through fluvial or glaciofluvial sediments into the underlying lacustrine sediments. At some locations, shallow sediment cores were taken with hand-held soil augers. Water well logs filed at the Division of Water, Ohio Department of Natural Resources, were studied for correlations of deeper valley fill sediments.

Selected samples from steam bank exposures as well as hand- and power-augured drill cores were air dried and disaggregated using mortar and pestle in the lab. Sediment particle size analysis utilized sieves and the pipette method (Gee and Bauder 1986). Calcite, dolomite, and total calcite equivalent contents of calcareous samples were determined by the rate of CO_2 evolution using a Chittick apparatus following the methodology of Dreimanis (1962).

RESULTS AND DISCUSSION

Overview of Glacial Lake Licking

The Glacial Lake Licking basin includes the main stem of the modern Licking River whose previous westward path was blocked by ice advancing from the west. The eastward limit of the ice advance is not clearly expressed topographically. Subsurface borings and foundation excavations performed during the construction of the Longaberger Corporate Headquarters (Fig. 3) reveal a complex stratigraphy of glacial till, lacustrine, and perhaps glaciodeltaic deposits suggestive of an ice-marginal location (BBC&M Engineering 1995). The Amanda silt loam, a soil formed in late Wisconsinan till, is mapped in small hollows up to elevations of about 275 m (900 ft) two km to the southwest of this site but is not mapped to the east (Parkinson and others 1992).

The highest elevation of the impounded lake is uncertain but would have been limited either by the elevation of the glacial fill at Hanover or more likely by the elevation of the divide where Black Hand Gorge was subsequently cut. This divide may have been breached and eroded repeatedly with successive ice advances. The impounded lake may have extended into and would have received significant discharge and sediments from Rocky Fork draining from the north, Claylick and Little Claylick entering from the south, and Brushy Fork entering from unglaciated terrain to the southeast. The terrain and relief of the contributing tributary basins are similar and the regional lithology changes only modestly with the eastward bedrock dip. The basins do differ significantly, however, in their glacial histories and in the distributions of Pleistocene deposits. Therefore erosion did yield somewhat different material to different embayments of the glacial lake.

In Licking County, the Mentor, Glenford, Fitchville, and Luray soil series represent a drainage association of soils developed in glaciolacustrine deposits on Wisconsinan terraces and lake plains (Parkinson and others 1992). Unfortunately, these soils are defined by their silty parent material and drainage conditions, reflected in soil horizonation and mottling pattern, not by the actual origin of the silt and hence cannot be used to map distributions of former lakes. In the Claylick and Little Claylick basins, for example, the Mentor soil is mapped up to elevations of at least 260 m (860 ft) in the main valleys and 284 m (930 ft) in small tributary valleys. There is no well-defined upper limit to its distribution. In addition, the soil can be found on moderately sloping terrains that seem inconsistent with a lacustrine origin. Many of these soil bodies likely developed in some mixture of loess and silty colluvium rather than lake sediment. Biopedoturbation associated with soil development makes it difficult to distinguish these materials from lacustrine silt within the solum. While this study made use of the soil survey data for general patterns, it necessarily relied on stream bank exposures and deeper cores to identify and characterize lacustrine sediments within the basin.

The best exposures of fine-grained lacustrine sediments occur discontinuously along stream banks where modern channels are actively cutting into high terrace remnants (typically capped by Chili loam soils) in the lower reaches of tributary valleys of the Licking River between Newark and Hanover. Terrace cutbanks at these locations reveal dense, cohesive, commonly parallel-laminated, calcareous silt unconformably overlain by 2.0 to 8.0+ m of fluvial sand and gravel topped by 0.4 to 1.0 m of silt loam to very fine-sandy loam (Figs. 4, 5). Stream channel incision and lateral migration following the deposition of the high terrace sand and gravel has eroded both the terrace deposits and the underlying lacustrine sediment such that the lake silt is not exposed in banks along most low terraces and modern floodplain reaches. Where present, the cohesive silt resists channel erosion and frequently forms ledges extending out into the channel below the gravel bank. The presence of similar cohesive, calcareous silt in numerous borings into terraces and on floodplains below the depth of the modern channel bed suggests that this material represents a laterally continuous lacustrine deposit (Fig. 3).

The elevations of clearly-identifiable lacustrine sediment extend from an elevation of 228 m (748 ft) under the floodplain of the Licking River to 248 m (813 ft) in lower Rocky Fork and 252 m (825 ft) in middle Brushy Fork, to 255 m (838 ft) at Sleepy Hollow on the south flank of Licking Valley near the probable ice front. Several sites on dissected Illinoian surfaces and in tributary valleys reveal lacustrine-like deposits up to at least 254 m (835 ft). Thus, the lake extended to a maximum elevation of at least 254 m (835 ft) with a maximum depth of at least 25-30 m.

Composition of Lacustrine Sediments

The texture of bulk samples of lacustrine sediment ranged from fine silty clay (D_{50} = 0.002 mm) to fine sandy silt (D_{50}= 0.030 to 0.060 mm). The mean particle diameters are typical for underflow sedimentation in distal regions of glacier-fed lakes (Ashley and others 1985). Note that the data presented in Table 1 is limited

TABLE 1

Mean particle size statistics and mean carbonate contents for groups of lacustrine and diamict samples from different basins in the Glacial Lake Licking drainage.

Area	Material	D_{50} (mm)	D_{50} (ϕ)	Inman σ_ϕ*	Carbonate (%)	Cal/Dol
Lower Rocky Fork (7)**	Lacustrine	0.0048	7.7 ± 1.4	-3.0 ± 0.8	9.0 ± 2.9	0.25 ± 0.06
Lower Claylick (3)	Lacustrine	0.0055	7.5 ± 1.4	-3.4 ± 0.4	11.4 ± 2.4	0.37 ± 0.12
Lower Brushy Fork (6)	Lacustrine	0.022	5.5 ± 0.4	-2.3 ± 0.5	18.5 ± 1.1	0.09 ± 0.05
Licking Valley (4)	Lacustrine	0.0048	7.7 ± 0.8	-3.1 ± 0.7	9.7 ± 2.4	0.34 ± 0.05
Licking Valley (3)	Diamict (Till)	0.013	6.3 ± 0.1	-5.7 ± 0.4	12.1 ± 1.3	0.36 ± 0.02

* $(D(\phi_{16}) + D(\phi_{84}))/2$; ** # of samples

to those samples that appeared to be lacustrine from their uniformity or presence of laminations. Note also that variations in sediment texture within and among laminations, that appear to be fairly small under microscopic examination, are masked by bulk sampling. Brushy Fork samples were on average considerably coarser than those from the other basins.

The lacustrine sediments in the main valley and in Claylick and Rocky Fork valleys have similar carbonate contents (9-12%) to the tills to the west in the main valley suggesting a direct glaciofluvial or indirect glacio-eolian sediment source for those lake deposits (Table 1). The relatively high carbonate values for Brushy Fork sediments suggest an additional carbonate source, likely the Maxville, Upper Mercer, and Vanport limestones that are more extensive in that basin (DeLong 1972). The Brushy

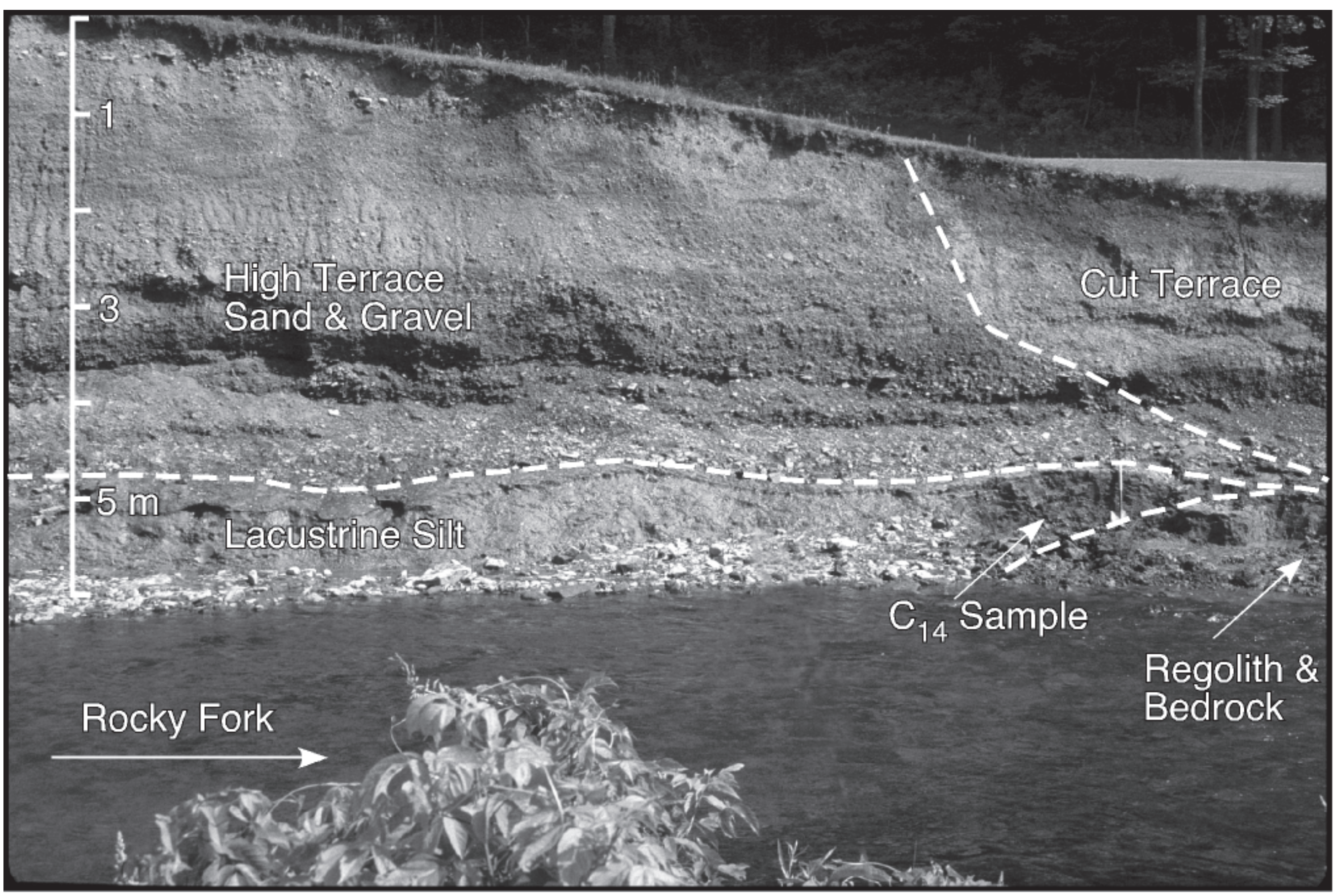

FIGURE 4. Photo of the Cartnal-Postle site on lower Rocky Fork showing south end of high terrace with fine-grained lacustrine sediment overlain by fluvial sand and gravel, lower cut terrace, and location of organics sampled for radiocarbon dating at contact between regolith and overlying lacustrine silt (scale bar approximate for left edge of photo).

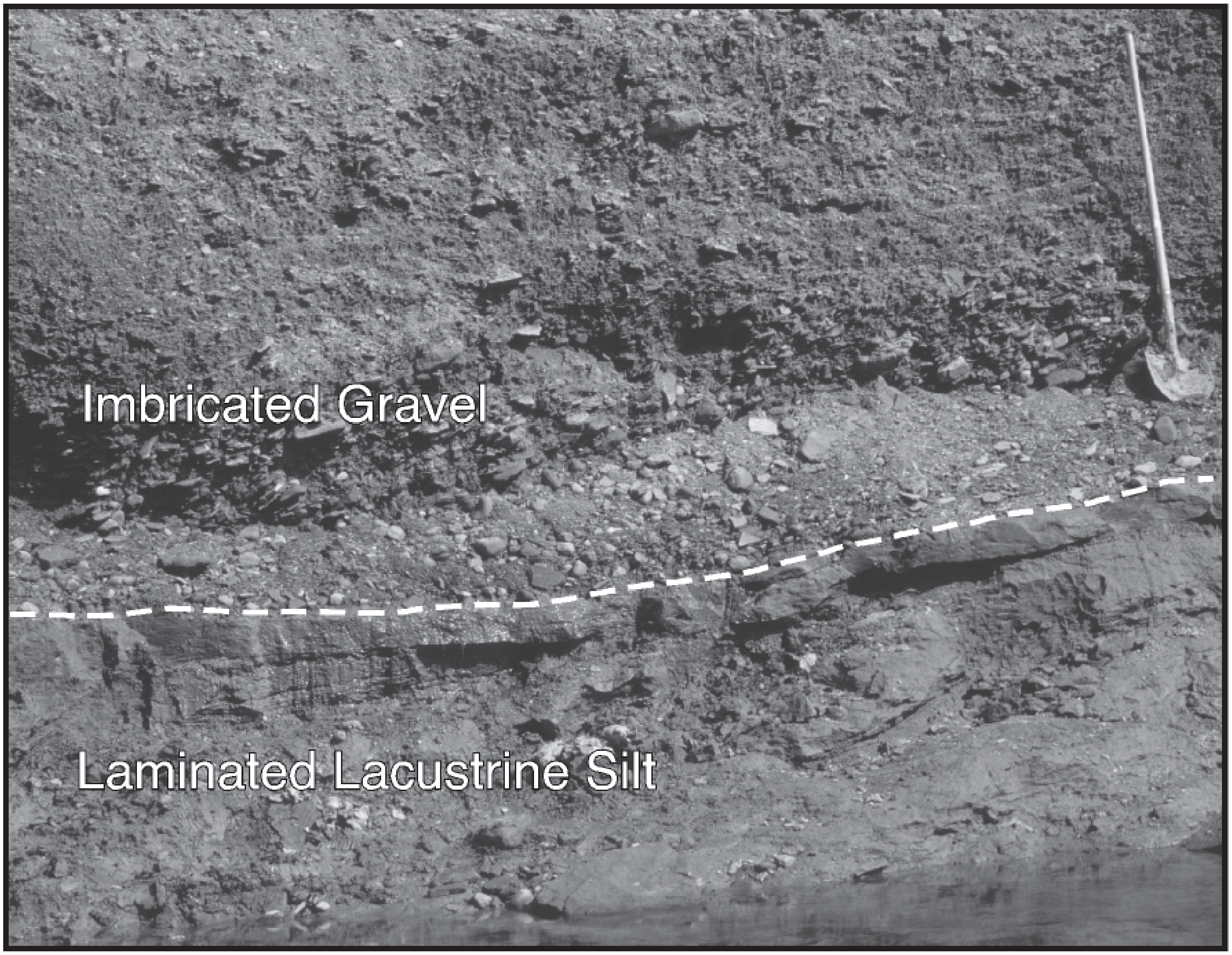

FIGURE 5. Photo of Cartnal-Postle site on lower Rocky Fork showing imbricated gravel, wavy contact, and laminated lacustrine deposit (shovel is 1.45 m long).

Fork sediments also have a much lower calcite/dolomite ratio than the other basins. The lower portion of the Maxville limestone is dolomitic in some places in nearby Muskingum County, whereas the Upper Mercer and Vanport limestones are less so (Lamborn 1951). A possible explanation for the low calcite/dolomite ratios would be the preferential solution of calcite, and therefore the concentration of dolomite, during the weathering, erosion, and transport of the local carbonate sediment.

In stream bank exposures, the fine sediment is generally devoid of visible organics and shells fragments. No exposures reveal obvious unconformities in sedimentation. The fine texture, the presence of 0.5-2.0 mm thick parallel lamina stratification (more easily visible where oxidation is present), and the apparent lateral basin-wide continuity of the sediment beneath the terrace gravels strongly suggest sedimentation into an extensive body of water (Ashley and others 1985). Unfortunately, the thickness of bank exposures was limited to about 2.0 m at the Cartnal-Postle site (Figs. 4, 5, 6) and to about 2.5 m along Claylick Creek. Several deep, continuous cores would be necessary to more fully investigate the relationship between the varve-like lamina and the lake's history.

Dating Lake Sediments

Radiocarbon dates from two localities indicate a Late Wisconsinan age for the lacustrine material. At the Cartnal-Postle site (Figs. 4, 6), compacted leaf and stem fragments at the contact between calcareous gray silt and underlying sandy/cobbly sandstone regolith at an elevation of 234 m (768 ft) yielded a conventional radiocarbon age of 33,440 ± 1060 years BP (Beta-99659). This date is somewhat problematic in that it predates the arrival of Late Wisconsinan ice into the basin by more than 10,000 years (Pavey and others 1999). The organics may not be directly linked to the basin-wide lacustrine event, but they do indicate that the exposed lacustrine sediment in this area is of late Wisconsinan age.

In a channel bank exposure in middle Brushy Fork valley (Figs. 3, 7), fine organic material at the upper contact of weakly calcareous, gray, laminated silt yielded an AMS radiocarbon date of 21,660 ± 120 yrs BP (Beta-102848). The Brushy Fork silt, at an elevation of 248 m (814 ft), is conformably overlain by 50 cm of fine sand that is overlain by about 120 cm of imbricated cherty

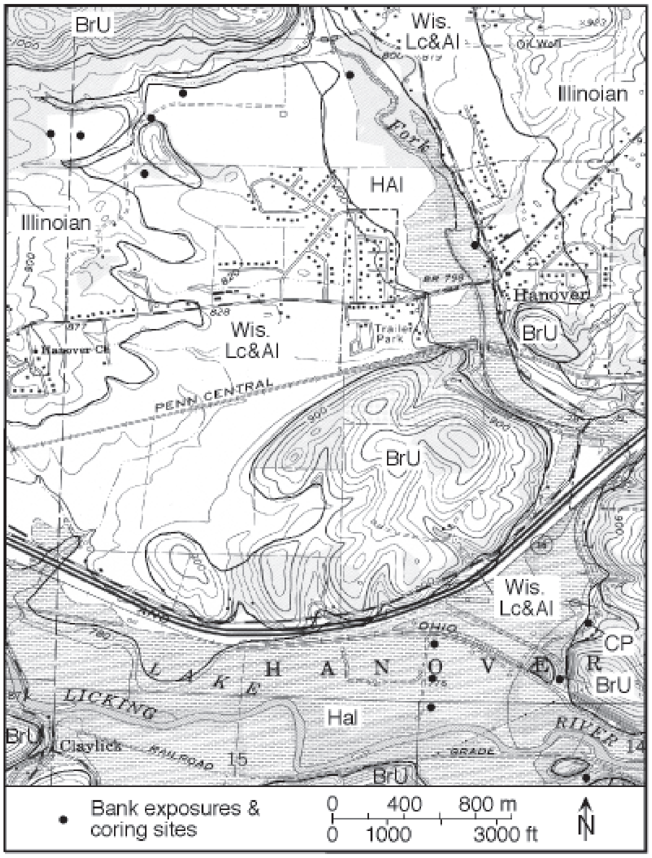

FIGURE 6. Topographic map of Lower Rocky Fork basin showing bank exposure and coring sites (CP indicates Cartnal-Postle bank exposure with radiocarbon date) and the general distribution of bedrock uplands (BrU), dissected Illinoian drift (Illinoian), Wisconsinan terraces with lacustrine, fluvial and eolian sediment (Wis. Lc&Al), and Holocene alluvial deposits (HAl); entrance to Black Hand Gorge in southeast corner; base map from Hanover Quadrangle, 7.5 minute series.

gravel. Two cores taken within 170 m of the modern channel along a 350 m transect southward across the Brushy Fork terrace (Fig. 7) reveal lacustrine materials at similar depths to those in the bank exposure with overlying interbedded sand/gravel and silty units. The next core at 230 m was entirely silt to very fine sand lacustrine material to an elevation of 251 m (824 ft) topped with a probable loess cover. This 5.0+ m core showed no subsurface weathering zone, which supports a Late-Wisconsinan age for the lake sediment. The core at 350 m on the lower footslope was similar and was capped with what appeared to be poorly sorted silt, sand and gravel colluvium. While uncertainty remains, the fluvial sand and gravel in the valley center appears to be inset into the lacustrine sediment in a cut and fill sequence as the environment changed from lacustrine to fluvial. Lateral relationships suggest the gravel in the stream bank is not conformable with the underlying silt but does indicate that the lacustrine sediment could only have extended an additional 2.0+ m above the dated sediment before the lacustrine regime ended as the Gorge was cut. Note that this valley floor pattern is widely expressed through the region where Chili loam soils (terrace gravels) are flanked by Mentor and Glenford silt loam soils on the valley floor margins.

The Brushy Fork date is similar to a 21,400 ± 600 yrs BP date for wood recovered from the basal zone of a 18 m thick till unit in the South Fork Licking valley about 7.0 km southwest of Newark. Goldthwait (1958) interpreted this till to represent the initial advance of the Late Wisconsinan Scioto Lobe into the region. The date is on the early side of the 21,000 yrs BP average date for the maximum extent of the early Late-Wisconsinan ice advance (Rosengreen 1974). Integrating the Brushy Fork observations with this data on the regional ice advance, the Gorge was likely cut quite early in the Late Wisconsinan, shortly after ice arrived on the scene.

Upper Limits of Lacustrine Sedimentation

To help define the upper limit of lacustrine sedimentation, tributary valley floors and dissected Illinoian drift surfaces at elevations of 250-260 m (820 to 850 ft) were cored (Figs. 6, 7). Some locations reveal silty profiles in which possible lacustrine sediment occurs within modern soil profiles. The oxidized and bioturbated material at these locations has lost any resemblance to cohesive laminated lacustrine sediment. Similarly textured late glacial eolian silt and reworked colluvial silt on footslope and valley floor surfaces cannot be readily differentiated from lake sediments within soil profiles. At some sites, silty-clay material extended well down through the soil C horizon, at depths below 125 cm, and here a lacustrine origin could be more confidently assigned.

In the Claylick and Little Claylick basins and in the buried valley area west of Hanover, sand and gravel

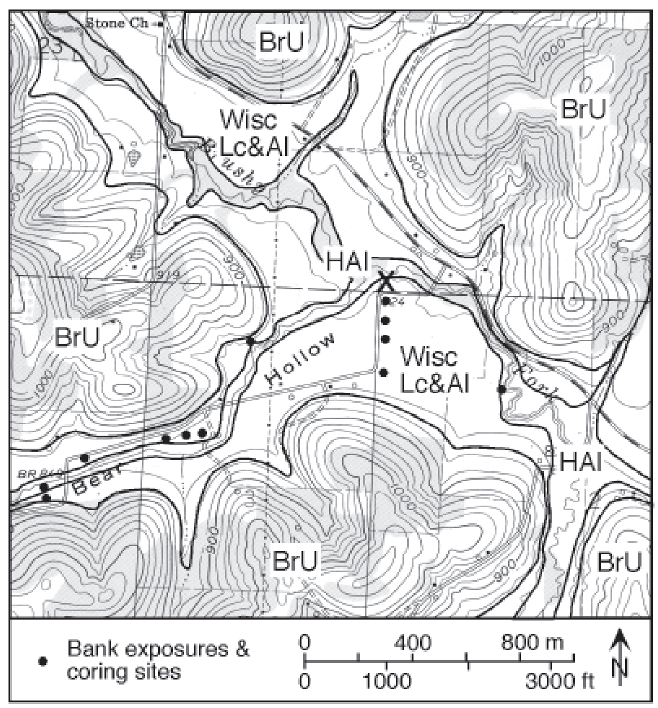

FIGURE 7. Topographic map of the Bear Hollow and Brushy Fork confluence showing coring sites (X indicates bank exposure with radiocarbon date) and the general distribution of bedrock uplands (BrU), Wisconsinan terraces with lacustrine, fluvial and eolian sediment (Wis. Lc&Al), and Holocene alluvial deposits (HAl); base map from Toboso Quadrangle, 7.5 minute series.

deposits of probable Illinoian age occur through a range of elevations on the now dissected terrain. Several flat surfaces above 258 m (845 ft) had 120+ cm of silt loam (mainly Wisconsinan loess) over sand and gravel. At surface elevations of 250-255 m (820-836 ft) the stratigraphy was less consistent. Silt caps were usually thinner but several cores revealed what appeared to be lacustrine sediment at elevations of about 253 m (830 ft). Many sites were on modest slopes and it is possible that erosion through the late glacial period may have removed any lacustrine sediment that had been deposited. Given the modest number of cores taken from these locations, a clear upper limit to lacustrine sediment cannot confidently be assigned at this time.

Terrace Sand and Gravel

The contact between the post lacustrine sand and gravel and the underlying dense, cohesive, calcareous silt is typically wavy and unconformable (Fig. 4). Few exposures reveal obvious channel cuts into the fine sediment, but observations are restricted because the lengths of bank exposures are limited to tens of meters at most. At many localities, the upper zone of lacustrine silt in contact with overlying gravel is oxidized. We interpret this as post-depositional oxidation linked to the aeration of the gravel and not a former weathering surface. The fluvial sand and gravel unit shows poorly developed parallel bedding characteristic of shallow braided channels (Figs. 4, 5; Church and Gilbert 1975). These deposits are very similar sedimentologically to pro-glacial outwash deposits that occur in Wisconsinan outwash terraces mapped further to the west (Forsyth 1966). Lacking direct glacial sources, the braided character of the stream channels in tributary valleys must have been due to a relatively heavy channel bed load resulting from high rates of sediment delivery in a periglacial landscape (Amba and others 1990; Frolking and Szabo 1998; Mol and others 2000). Fining-upward sequences or fine-grained channel fills characteristic of meandering channels have not been found in the terrace deposits.

Most of these terrace remnants are mapped as Chili loam soils (Parkinson and others 1992) and reveal modern soil development that extends through the loam cap into the underlying gravel. No clear cut-and-fill structures or weathering zones within the sand and gravel have been observed suggesting relatively rapid deposition without significant periods of subaerial exposure. Soil profile development appears to be on par with Ockley soil profiles developed in silt over late-Wisconsinan outwash in the central and western parts of the Licking River basin (Parkinson and others 1992) and clearly lacks the depth of leaching and soil development found in Illinoian outwash terraces. Integrating these stratigraphic and pedogenic observations, we interpret the sand and gravel as well as the overlying loamy cap to be Late Wisconsinan in age.

Exposures and cores along a stepped-terrace sequence in the Licking River valley near the probable ice margin (see terrace delineations in Forsyth 1966) reveal generally thin (1.0-3.0 m) calcareous gravel deposits over calcareous glacial diamict and lacustrine deposits. This suggests a degradational channel regime, perhaps in response to both ice margin movement and the continued cutting of the Gorge and lowering of the local base level. Some terraces such as at the Cartnal-Postle site (Fig. 4) expose as much as 6.0 m of sand and gravel suggesting valley floor aggradation on top of the lake deposits before significant channel degradation took place.

Basin-to-basin variations in the composition of the gravel also suggest a late-Wisconsinan age. In lower Rocky Fork, which had no significant Wisconsinan outwash input (Pavey and others 1999), a major sediment source would have been erosion of the extensive Illinoian outwash fills found principally in the tributary Wilkins Run valley (Forsyth 1966). The upper 3.0-5.0 m of this Illinoian gravel has been leached of carbonates. The Wisconsinan terrace gravels present in lower Rocky Fork are also leached suggesting mobilization and redeposition of the upvalley Illinoian deposits. In the Claylick and Little Claylick basins, calcareous Illinoian diamicton is abundant and Wisconsinan outwash may have entered the basin via a drainage breach in upper Claylick Creek. In these basins, the terrace gravel is generally calcareous. Gravels in the lower reaches of the unglaciated Brushy Fork basin are weakly calcareous and are dominated by flint. Flints from the Upper Mercer limestone and Vanport limestone of the Pottsville and Allegheny groups, respectively, are present along upper valley sides and ridgetops within the basin (DeLong 1972). While it is not yet clear to what degree the Brushy Fork terrace gravels reflect a reworking of older valley floor deposits as opposed to the erosion of cherts from valley sides and low order tributaries, the gravel deposits indicate significant mobilization, transportation, and deposition of coarse sediments during this periglacial phase.

CONCLUSIONS

Estimates of the age of Black Hand Gorge have narrowed considerably from Pleistocene (Tight 1894a,b) to Illinoian (Dove 1960; Malcuit and Bork 1987) as understanding of the region's glacial history has come into better focus over the past century. Field relationships and radiometric data presented here both reduce the Gorge's age and narrow its period of formation to a relatively short time span in the early Late Wisconsinan. Given the relatively sluggish rate of landscape change in central Ohio through the Holocene, erosional and depositional activity during the late glacial was truly dramatic. While more radiometric dates and deeper cores are needed to better constrain the lake's history, it seems clear that glacial ice advance, lake impoundment and sedimentation, gorge cutting and glaciofluvial valley sedimentation occurred within a few thousand years. Located at the southern reaches of the Late-Wisconsinan Laurentide ice margin, ice was only present within the Licking River basin for about 6000 years (Frolking and Szabo 1998).

The Late-Wisconsinan cutting of Black Hand Gorge and subsequent development of the modern Licking

River drainage system presented here is supported by the presence of thick Late-Wisconsinan deposits in the Raccoon Creek and South Fork tributaries to the west and southwest of Newark. Buried wood lying 3.0 m above bedrock and overlain by 28+ m of diamict on the northern flank of the South Fork valley in east-central Harrison Township, Licking County, dated to 44,130 ± 1500 yrs BP (Beta-91906) indicating thick Late-Wisconsinan deposits in the South Fork valley. A 35 m core recovered from the floodplain of Raccoon Creek at Granville contains 22+ m of lacustrine and overbank deposits above wood dated to 15,620 ± 110 yrs BP (Beta-91907). These sediments indicate substantial Late-Wisconsinan fill and pre Late-Wisconsinan valley floor elevations that were too low to have drained eastward through the Gorge. Prior to the Late-Wisconsinan ice advance, Raccoon Creek would have joined the ancestral Licking River tributaries from the north and east at Newark and would have then flowed through the South Fork valley toward the southwest where even thicker Late-Wisconsinan deposits have been noted (Frolking and Szabo 1998).

Field relationships to date have not resolved the maximum elevation of Glacial Lake Licking during the Late Wisconsinan. The lack of observed deltas at the probable margins of the glacial lake can likely be explained by fluctuating lake levels as evidenced by some cores and exposures and by fluvial erosion within tributary valleys following gorge cutting. The presence of the uneroded outwash terrace surface north of Hanover at 275 m (900 ft) indicates the bedrock divide in the vicinity of the Gorge must have been lower to allow for outflow in any subsequent ice advance, whether Illinoian or Wisconsinan. The valley walls through the Gorge have a distinct break in slope as they steepen into the inner Gorge at about 275 m elevation. This might indicate relatively recent incision from that elevation but might also reflect lithologic control. The contact between the massive Black Hand sandstone and thinly bedded units of the overlying Logan Formation occurs at about that elevation.

In the future, a careful geomorphic examination of materials, slopes, and tributary valley forms within the Gorge reach should provide new insights into its evolution now that the timing of the Gorge incision is better constrained. Radiometric dates from terrace sequences and materials to the east (downstream) of the Gorge would help constrain the period of cutting, and the composition of those sediments could provide information on the mechanics of gorge cutting. A comparison of the form of Black Hand Gorge with other gorges in the region might help to better constrain their erosional histories and lead to field-based studies of their development.

ACKNOWLEDGMENTS. We thank Denison University's Thomas F. Bates Geology Research Fund for the two radiometric dates, and Gregory A. Schumacher and one anonymous reviewer for their careful reviews of the manuscript.

LITERATURE CITED

Amba EA, Smeck NE, Hall GF, Bigham JM. 1990. Geomorphic and pedogenic processes operative in soils of a hillslope in the unglaciated region of Ohio. Ohio J Sci 90:4-12.

Ashley GM, Shaw J, Smith ND. 1985. Glacial Sedimentary Environments. Society of Economic Petrologists and Mineralogists Short Course, 16. 246 p.

BBC&M Engineering, Inc. 1995. Preliminary subsurface investigation, Longaberger Headquarters Complex, Newark, OH. Report to Longaberger Construction Co. 23 p + 58 plates.

Bork KB, Malcuit RJ. 1979. Paleoenvironments of the Cuyahoga and Logan Formations (Mississippian) of central Ohio. Geol Soc of America Bull. 90:1782-1838.

Brockman CS. 1998. Physiographic Regions of Ohio. Ohio Dept of Nat Resources, Div of Geological Surv. Map with text.

Carney F. 1907. The glacial dam at Hanover, Ohio. Bull Scientific Laboratories Denison Univ. 13:139-53.

Church M, Gilbert R. 1975. Proglacial fluvial and lacustrine environments. In: Jopling AV, McDonald BC, editors. Glaciofluvial and Glaciolacustrine Sedimentation. Soc of Economic Paleontologists and Mineralogists. Special Publ 23. p 4-21.

Coffee GN. 1958. Major glacial drainage changes in Ohio. Ohio J Sci 58(1):43-9.

DeLong RM. 1972. Bedrock geology of the Flint Ridge area, Ohio. Ohio Dept of Nat Resources, Div of Geological Surv. Report of Investigations No. 84. Map with text.

Dove GD. 1960. Water resources of Licking County, Ohio. Ohio Dept of Nat Resources, Div of Water. Bull 36. 96 p.

Dreimanis A. 1962. Quantitative gasometric determination of calcite and dolomite using a Chittick apparatus. J Sedimentary Petrology 32(3):520-29.

Forsyth JL. 1966. Glacial map of Licking County. Ohio Dept of Nat Resources, Div of Geological Surv. Rept of Investigation 59. Map with text.

Frolking TA, Szabo JP. 1998. Quaternary geology along the eastern margin of the Scioto Lobe in central Ohio. Ohio Dept of Nat Resources, Div of Geological Surv. Guidebook 16. 40 p.

Gee GW, Bauder JW. 1986. Particle-size analysis. In: Klute A, editor. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. Agronomy Monograph No. 9, 2nd ed. Madison: American Soc of Agronomy. p 383-411.

Goldthwait RP. 1958. Wisconsin age forests in western Ohio, I. Age and glacial events. Ohio J Sci 58:209-19.

Lamborn RE. 1951. Limestones of Eastern Ohio. Ohio Dept of Nat Resources, Div of Geological Surv, 4th Series. Bull 49. 364 pp.

Leverett F. 1902. Glacial formations and drainage features of the Erie and Ohio Basins. US Geological Surv Monographs. Vol XLI. 802 p.

Malcuit RJ, Bork KB. 1987. Black Hand Gorge State Nature Preserve: Lower Mississippian deltaic deposits in east-central Ohio. Geol Soc of America Centennial Field Guide: North-Central Section. p 411-14.

Melhorn WN, Kempton JP. 1991. The Teays system: a summary. In: Melhorn WN, Kempton JP, editors. Geology and Hydrogeology of the Teays-Mahomet Bedrock Valley System. Geol Soc of America. Special Paper 258. p 125-8.

Mol J, Vandenberghe J, Kasse C. 2000. River response to variations of periglacial climate in mid-latitude Europe. Geomorphology 33:131-48.

Parkinson R, Wigginton M, Jenny PC. 1992. Soil survey of Licking County, Ohio. US Dept of Agriculture Soil Conserv Serv. 279 p with 81 sheets.

Pavey RR. 1995. Bedrock topography of the Hanover, Ohio quadrangle. Ohio Dept of Nat Resources, Div of Geological Surv. Open-File Map BT-C3A3.

Pavey RR, Goldthwait RP, Brockman CS, Hull DN, Swinford EM, Van Horn RG. 1999. Quaternary Geology of Ohio. Ohio Dept of Nat Resources, Div of Geological Surv. Map 2.

Rosengreen TE. 1974. Glacial geology of Highland County, Ohio. Ohio Dept of Nat Resources, Div of Geological Surv. Rept of Investigations 92. 36 p.

Stout W, Ver Steeg K, Lamb GF. 1943. Geology of water in Ohio. Ohio Dept of Nat Resources, Div of Geological Surv. Bull 44, 4th series. 694 p.

Teller JT, Goldthwait RP. 1991. The Old Kentucky River: a major tributary to the Teays River. In: Melhorn WN, Kempton JP, editors. Geology and Hydrogeology of the Teays-Mahomet Bedrock Valley System. Geol Soc of America. Special Paper 258. p 29-41.

Tight WG. 1894a. A contribution to the knowledge of the preglacial drainage of Ohio, Part I. Bull Scientific Laboratories Denison Univ. 8:35-62.

Tight WG. 1894b. Lake Licking – A contribution to the buried drainage of Ohio. Ohio State Acad of Sci. 1st Annual Rept. p 17-20.